

Laboratoire d'Écologie de l'École Normale Supérieure, Paris, France;
Estación experimental San Ramón, Yurimaguas, Loreto, Peru

Soil macrofauna and land management in Peruvian Amazonia (Yurimaguas, Loreto)

PATRICK LAVELLE and BETO PASHANASI

With 4 figures

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1. Introduction

In natural environments of the humid tropics, soil macroinvertebrates are major regulating agents of soil processes which may affect both the physical and chemical fertility of soils (see e.g. LEE & WOOD, 1971; LAVELLE, 1984; LEE, 1985). They contribute to the formation of resistant macro-aggregate structures by ingesting and egesting soil, mixing it with organic residues, digging burrows and subterranean chambers, and transporting soil to the surface.

Soil macroinvertebrates regulate the mineralization and humification of litter and soil organic matter by the selective activation of dormant microflora at selected scales of time and space.

The abundance and structure of communities may vary greatly with climate, soil and vegetation conditions. In a given area, the type of vegetation has often been shown to be the major determinant factor, with forested areas having dominant epigeic above-ground litter feeding populations, and grasslands mainly endogeic root-litter and soil organic matter feeding populations (LAVELLE *et al.*, 1981; COLLINS, 1980; LAVELLE & KOHLMANN, 1984; LEAKEY & PROCTOR, 1987).

Land management generally results in dramatic and rapid changes of vegetation which are likely to greatly affect soil invertebrate communities. After clearing and burning primary forest and planting crops or pastures, the ecological functioning of soils obtains savanna-like patterns, with increased variability of temperature and moisture and modified nutrient cycling with changes in the quality, quantity and timing of organic inputs.

2. Sites and methods

2.1. Sites

The present study was performed at the Yurimaguas Experimental Station in the Peruvian Amazonia in May and June of 1986, during the rainy season. The aim was to evaluate the effect of land management on soil macroinvertebrate communities. Eleven different situations were considered:

- primary forest;
- 15 year-old secondary forest;
- traditional cultivation (first crop of cassava);
- low input cultivation (rice, first crop);
- high input cultivation (corn, first crop);
- traditional 10 year-old pastures, one “humid”, the other one “dry”;
- improved pasture with *Brachiaria humidicola* (RENDLE) SCHWEICK + *Desmodium ovalifolium* GUILL & PERR. (Leguminosae);
- *Centrosema pubescens* BENTH. (Leguminosae) pasture;
- six month “Kudzu” (*Pueraria phaseoloides* BENTH.) fallow after high input cropping;
- Pijuayo palm-trees (*Bactris gasipaes* RUNTH.) with a Kudzu cover.

Soils are ultisols with acid pH (4.0 to 4.5), topsoil clay contents ranging from 4 to 20 %; organic matter contents 1.7 to 3 %, Al saturation ranging from 25 to 80 %. Unfertilized plots have low nutrient contents, especially in available P (2 ppm in traditional system), K (0.11 meq/100 g) and Mg (0.45 meq/100 g).

2.2. Methods

The sampling method recommended in the TSBF programme was employed (LAVELLE, 1988a; ANDERSON & INGRAM, 1989): in each site, 10 samples of 25 cm $\times$ 25 cm $\times$ 30 cm were taken at regular 5 m intervals, along a line whose origin and direction had been chosen at random (fig. 1). The monoliths were hand-sorted in 4 successive strata (i.e., litter, 0–10, 10–20, 20–30 cm), and the invertebrates collected and conserved in 4 % formalin. In the laboratory they were separated into 42 broad taxonomic units (orders or families).

A further classification was made among five ecological categories as defined by BOUCHÉ (1971) and further extended by LAVELLE (1981):

- **epigeics** which feed and live in the litter;
- **anecics** which feed on litter but live in subterranean galleries (earthworms) or epigeic or endogeic nests (leaf-cutting ants, litter and wood feeding termites);
- **endogeics** which live and feed in the soil; these are divided into three groups according to the relative organic richness of the soil they feed on: **polyhumics** ingest a soil with a higher organic content than the bulk A1 horizon; **mesohumics** ingest the A1 soil as it is and **oligohumics** feed on the poor soil of deeper horizons.

3. Results

After compiling the 10 individual samples of each site into one, a principal component analysis was performed with the 11 elements to point out the major differences of invertebrate communities among types of land use, and to try to identify their origin.

Two factors account for 54 % of the total variance:

Factor I characterizes soils with low Al saturation, high silt and low sand contents, high Ca and Mg and high pH (table 1). In such soils, macrofauna has a low population density but high biomass, due to the colonization by the peregrine earthworm species *Pontoscolex corethrurus* MÜLLER, a mesohumic species which has invaded disturbed soils of all humid tropics of the world. Termites have low population densities, as well as Arachnida and other litter-dwelling epigeics. This fauna is concentrated in the 0–10 cm soil strata.

This factor differentiates forests from pastures, with cultures and fallows being in an intermediate position. It may be thus assigned to the **effect of the type of vegetation**.

The second factor accounts for 19.3 % of the variance. It characterizes soils with low acidity (i.e., concentration of acid ions) and relatively high nutrient contents and pH . Soil fauna have a low population density and biomass with an especially low abundance of litter-dwelling epigeics such as Myriapoda and Arachnida, with the concentration of individuals in the deep soil horizons.

This factor which separates crops and forests from improved pasture with a thick cover of Leguminosae and Gramineae, represents the effect of **physical protection of soil by vegetation cover**: in conditions of low protection, the epigeic litter fauna tends to disappear and frequent heating of soil in the upper horizons results in a relative accumulation of fauna in the deeper soil strata.

Two further factors which account for 14.1 and 10.4 % of the variance respectively, describe secondary effects of soil texture (high clay contents favouring Coleoptera) and high soil organic matter contents associated with high ant populations.

Four distinct situations may thus be distinguished: forests, crops, pastures, short fallows and palm tree plantations (fig. 1).

Primary forest has the highest taxonomic richness (41 units) and population density (4,304 ind $\cdot$ m⁻²), and a high biomass (53.9 g $\cdot$ m⁻²) (tables 2, 3). 12.7 % of the fauna is found in the litter layer, but the soil is densely colonized down to 20 cm (fig. 3). Earthworm communities, dominated by litter feeding epigeic and anecic species, are the major components of biomass (52.3 %) followed by termites (15.8 %) and Myriapoda (11.5 %) (table 3, fig. 4).

The 15 year-old secondary forest has a rather similar community, though a much lower taxonomic

Table 1. Major correlations between factors extracted in the principal components analysis and soil and fauna variables.

Soil		Fauna	
Factor I: 34.7 % Variance explained – Identified as Vegetation type			
Al %	−0.84	P. Density	−0.68
Silt	0.77	Biomass	−0.81
Sand	−0.71	<i>P. corethrurus</i>	0.91
Ca	0.77	Termites	−0.80
Mg	0.50	Arachnida	−0.50
pH	0.67		
Factor II: 19.3 % Variance explained – Identified as effects of shade			
Acidity	−0.62	[%] in 20–30 cm strata	0.84
K	0.50	Myriapoda	−0.71
Mg	0.40	Arachnida	−0.59
pH	0.46	P. Density	−0.54
		Biomass	−0.54

Table 2. Taxonomic richness, mean abundance and biomass of macroinvertebrates in different types of land-use at Yurimaguas.

Type of land-use	No. of taxonomic units	Mean popul. density m ^{−2}	S.E. of density	Mean biomass g.fm.m ^{−2}	S.E. of biomass
Forests					
Primary Forest	41	4,304	933	53.9	8.54
Secondary Forest (15 years)	27	4,099	1,828	24.1	5.85
Crops (1st crop)					
High input maize	20	730	221	3.1	1.04
Low input rice	24	3,683	1,059	8.5	2.75
Traditional cassava	18	1,197	283	7.6	3.26
Pastures					
Improved <i>Bracharia-Desmodium</i> system	27	922	81	159.2	16.4
Traditional “moist” pasture	23	1,768	308	121.1	20.8
Traditional “dry” pasture	20	2,347	453	82.3	15.5
Fallows					
Six-months <i>Centrosema</i> after pasture	22	1,546	253	111.9	13.2
Six-months Kudzu (<i>Pueraria phaseoloides</i>) after high input crop.	23	2,214	969	15.5	6.2
Peach-palm + Kudzu cover	32	1,858	380	93.9	25.2

richness (27 units), a similar population density (4,099 ind · m^{−2}) and lower biomass (24.1 g · m^{−2}). Vertical distribution is more concentrated towards the surface than in primary forest, with 19.2 % in the litter layer and 58.4 % in the 0–10 cm stratum.

Cropping results in a dramatic decrease of taxonomic richness (18–24 units) as well as population density (730–1,197 ind · m^{−2}) (with the exception of low input crops, where the

Table 3. Composition of Macroinvertebrate communities in different types of land use at Yurimaguas.

	Forests		Crops			Pastures				Fallows + Palm	
	Primary Forest	Second Forest	High Input	Low Input	Trad. System	Brach. Desmod	Tradit. moist	Tradit. Dry	Centro-sema	Peach palm	Kudzu
a. Population densities $\cdot m^{-2} \pm$ S.E. parentheses.											
Earthworms	120 (39.6)	85 (39)	14 (7.7)	10 (5.2)	13 (4.5)	740 (79)	573 (59.2)	474 (109.7)	546 (84.5)	218 (29.6)	341 (81.4)
Termites	3,240 (713)	3,570 (1,842.6)	306 (150.6)	3,142 (1,050)	368 (302)	11 (9.2)	366 (133)	629 (352)	544 (226)	1,147 (371)	1,547 (948.7)
Ants	555 (250)	290 (94.5)	272 (208.5)	370 (142.9)	640 (246.5)	68 (19.5)	706 (285)	1,147 (390)	256 (240)	285 (119)	147 (5.3)
Coleoptera	67 (20.2)	29 (10.9)	78 (31.2)	96 (27.4)	90 (40.9)	28 (14.8)	50 (13.3)	29 (7.9)	110 (20.3)	38.4 (8.0)	38 (7.2)
Arachnida	69 (21.5)	45 (11.2)	11 (3.6)	14 (4.7)	16 (3.6)	23 (8.0)	19.2 (5.5)	19 (8.6)	14 (6.4)	20.8 (6.2)	43 (15.5)
Myriapoda	69 (17.6)	27 (104.5)	0.0 (0)	16 (6.7)	0 (0)	10 (3.7)	19.2 (11.5)	0 (0)	26 (16.7)	30.4 (8.1)	48 (3.6)
Others	183 (22)	53 (49)	49 (26)	35 (59)	77 (59)	44 (17.2)	36.6 (5.8)	49 (40)	50 (19)	116.4 (53.9)	50 (35)
Total	4,303 (1,084)	4,099 (2,152)	730 (428)	3,683 (2,521)	1,197 (657)	922 (151)	1,768 (513)	2,347 (798)	1,856 (613)	1,546 (596)	2,214 (1,097)
b. Biomasses ($g \cdot m_h \cdot m^{-2}$) ¹⁾											
Earthworms	28.2 (8.9)	11.3 (4.0)	1.5 (1.5)	0.6 (0.6)	4.8 (3.4)	153 (17.0)	116.4 (22.0)	78 (17.1)	103.2 (13.2)	87.4 (25.05)	7.0 (2.2)
Termites	8.5 (2.3)	6.9 (2.7)	0.9 (0.4)	6.1 (2.7)	1.2 (1.0)	0.02 (0.03)	1.3 (0.38)	1.6 (0.9)	2.75 (1.15)	4.74 (2.34)	7.9 (4.0)
Ants	0.7 (0.2)	0.7 (0.5)	0.1 (0.1)	0.2 (0.07)	0.4 (0.2)	0.1 (0.06)	0.8 (0.3)	0.5 (0.2)	0.2 (0.2)	0.2 (0.07)	0.1 (0.03)
Coleoptera	1.6 (0.7)	0.6 (0.3)	0.6 (0.5)	0.4 (0.1)	0.8 (0.3)	0.17 (0.07)	1.3 (0.8)	0.6 (0.5)	3.2 (1.4)	0.39 (0.16)	0.1 (0.04)
Arachnida	3.1 (2.1)	2.0 (0.8)	0.01 (0.01)	0.03 (0.01)	0.6 (0.3)	0.04 (0.02)	0.03 (0.01)	0.02 (0.01)	0.46 (0.28)	0.09 (0.04)	0.2 (0.2)
Myriapoda	6.2 (4.0)	2.1 (1.6)	0 (0)	0.4 (0.2)	0 (0)	0.28 (0.15)	0.44 (0.3)	0 (0)	0.81 (0.49)	0.49 (0.2)	0.1 (0.06)
Others	5.6 (1.5)	0.5 (0.5)	0.08 (0.3)	0.8 (0.7)	0.2 (0.5)	5.59 (2.1)	0.93 (0.8)	1.6 (1.2)	9.3 (0.3)	0.59 (0.66)	0.5 (1.7)
Total	53.9 (19.7)	24.1 (10.4)	3.1 (2.8)	8.5 (4.4)	8.0 (5.7)	159.2 (19.4)	121.2 (24.6)	82.3 (19.9)	93.9 (17.0)	1,110.9 (28.5)	15.9 (8.2)

¹⁾ m_h = hygromass = fresh mass.

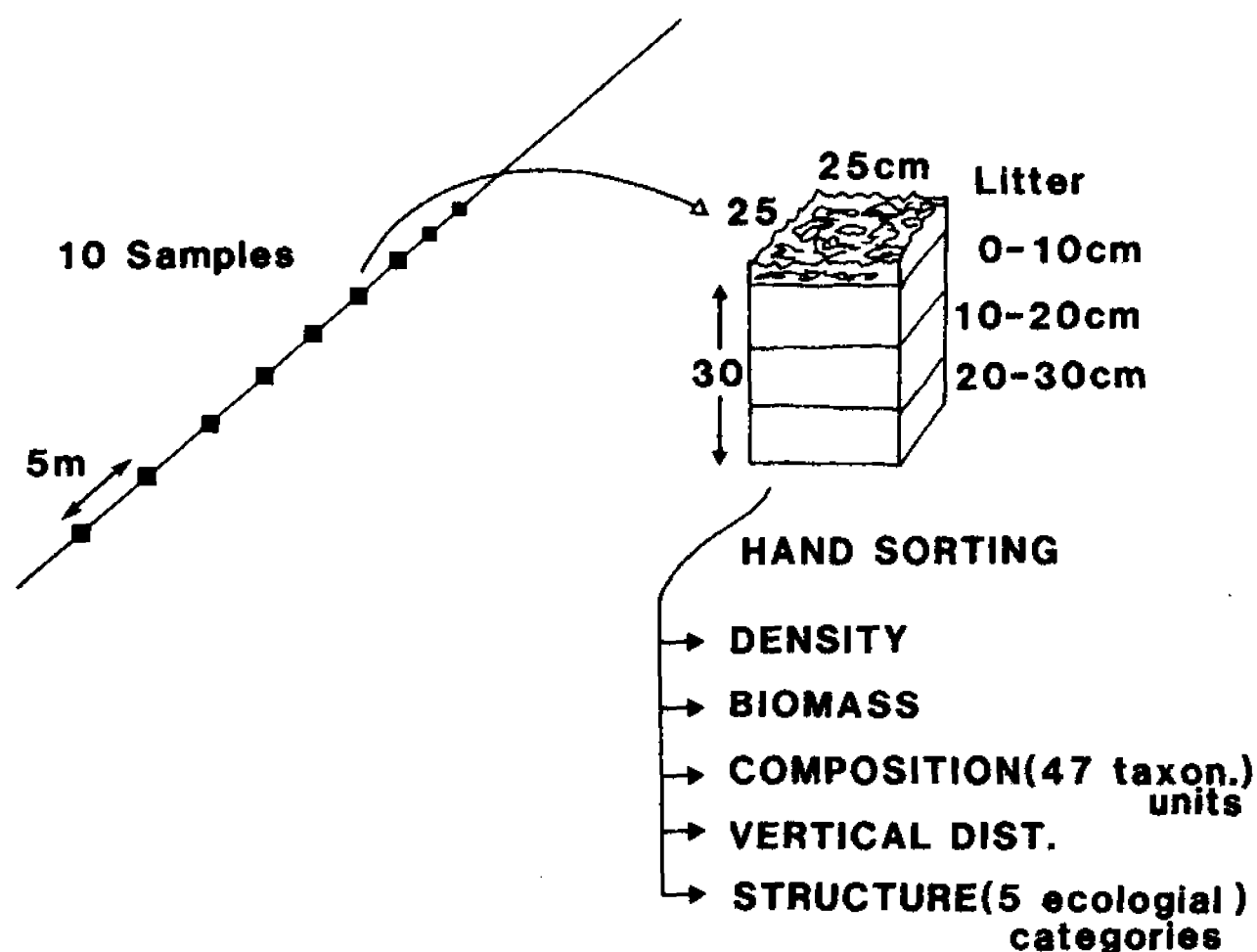


Fig. 1. Sampling methodology as designed by the Tropical Soil Biology and Fertility (TSBF, IUBS/UNESCO) programme (ANDERSON & INGRAM, 1988).

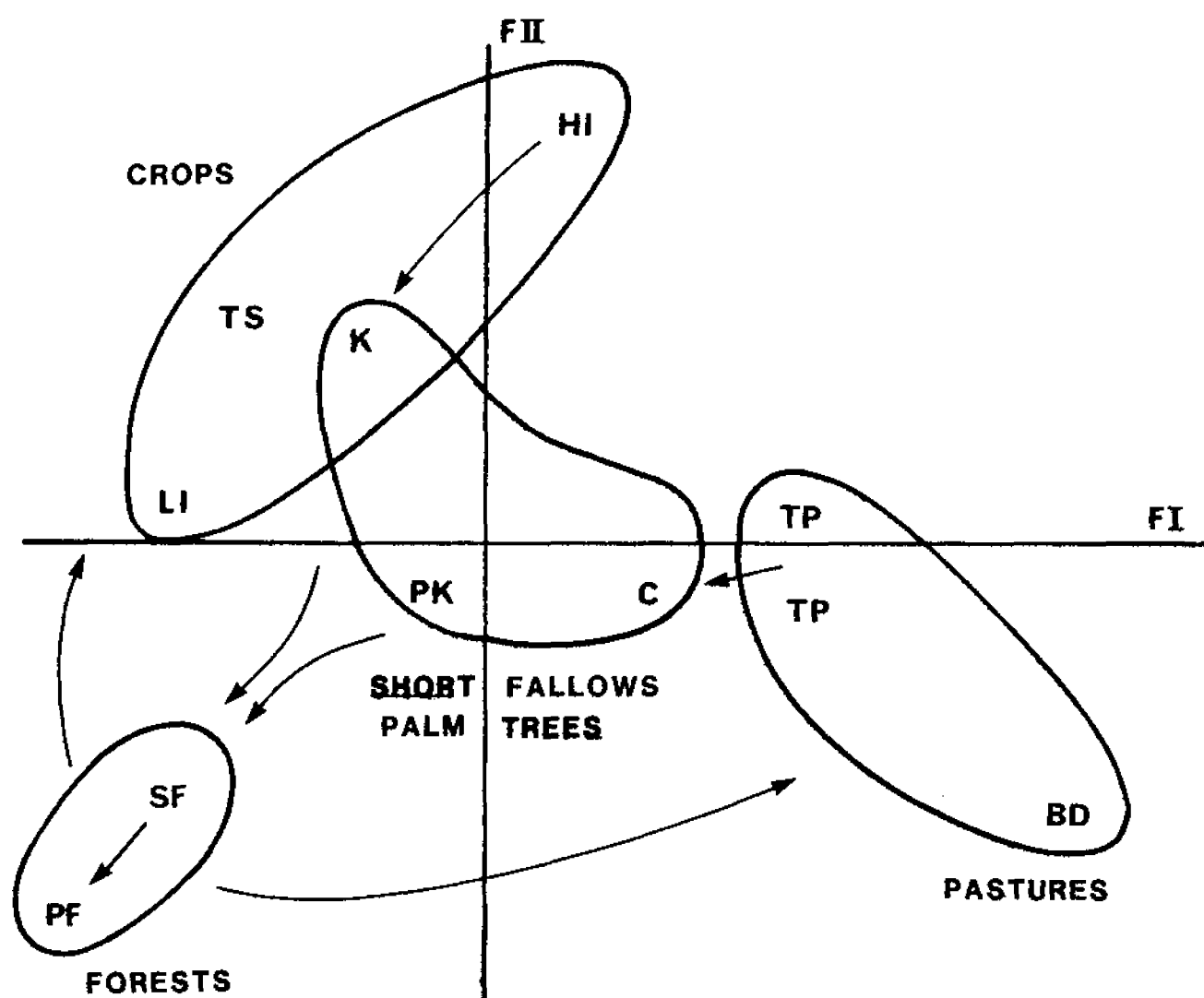


Fig. 2. Location of types of land-use in relation to the first 2 factors extracted by a principal components analysis. PF: primary forest; SF: secondary forest; LI: low input cultivation (rice, 1st crop); TS: traditional system (cassava, 1st crop); HI: high input (maize, 1st crop); K: Kudzu fallow (6 months after high input maize); C: *Centrosema pubescens* pasture; PK: peach-palm + Kudzu; B.D.: improved pasture (*Brachiaria* - *Desmodium*); T.P.: traditional pastures.

decrease is disguised by a local population of termites) and biomass ($3.1-8.5 \text{ g} \times \text{m}^{-2}$). Termites are the major component (29 to 71.8 % of biomass) while Coleoptera comprise 4.7 to 10 % and earthworms 7.1 to 60 %. Distribution along the soil profile is relatively deep with only 1.3 to 8.8 % in the litter and 12.5 to 19.5 % in the 20-30 cm layer.

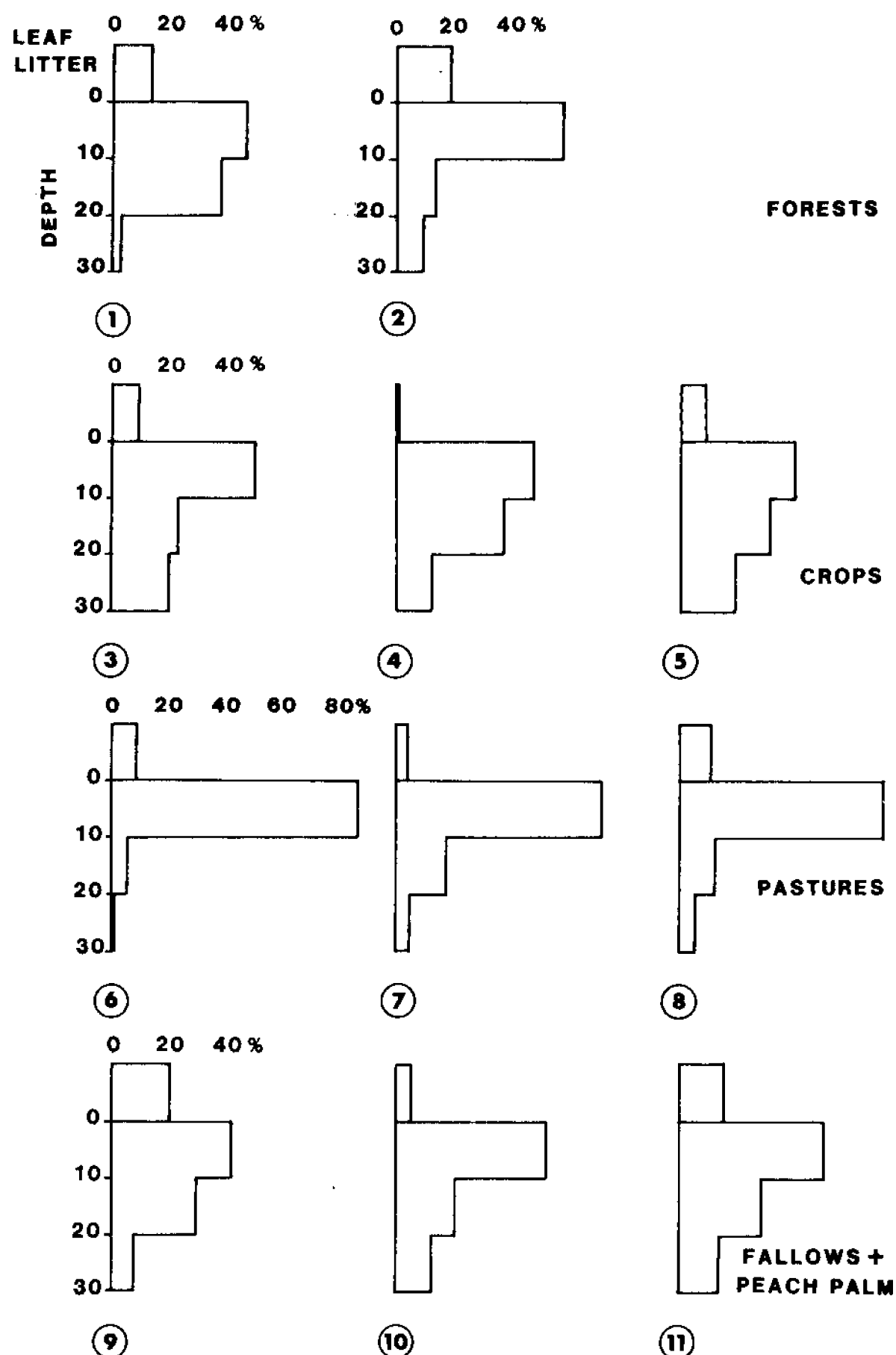


Fig. 3. Distribution in depth of individuals in the 11 types of land-use. 1: primary forest; 2: secondary forest; 3: low input cultivation (rice, 1st crop); 4: traditional system (cassava, 1st crop); 5: high input maize (1st crop); 6: improved pasture (*Brachiaria* + *Desmodium*); 7–8: traditional pastures; 9: Kudzu fallow (6 months after high input maize); 10: *Centrosema pubescens* pasture; 11: peach-palm + Kudzu.

Pastures have very different communities with an extraordinary dominance of populations of the endogeic earthworm *Pontoscolex corethrurus* with biomasses of up $1.5 \text{ mg} \times \text{ha}^{-1}$ comprising up to 91 to 96 % of the total biomass. Other groups of some importance are termites (2.1 to 26.8 % of population density) and ants (5.9 to 48.8 %). Litter-dwelling populations represent only 4.3 to 20.6 % of individuals, most of them being concentrated in the upper 10 cm (42.1 to 86.4 %) (table 3, fig. 4).

Short fallows of Leguminosae Kudzu (six months after high input cropping) and *Centrosema* pasture following a pasture with Gramineae and Leguminosae retain characteristics of the system they followed, with continued low taxonomic richness, but increased population densities ($1,546$ to $2,242 \text{ ind} \cdot \text{m}^{-2}$), and a slight evolution towards the original forest situation. This is demonstrated by their localization nearer to the original forest in fig. 1. The association of palm-trees with a Leguminosae Kudzu cover appeared to be the most conservative system, with both elements of the primary forest and the newly introduced ones.

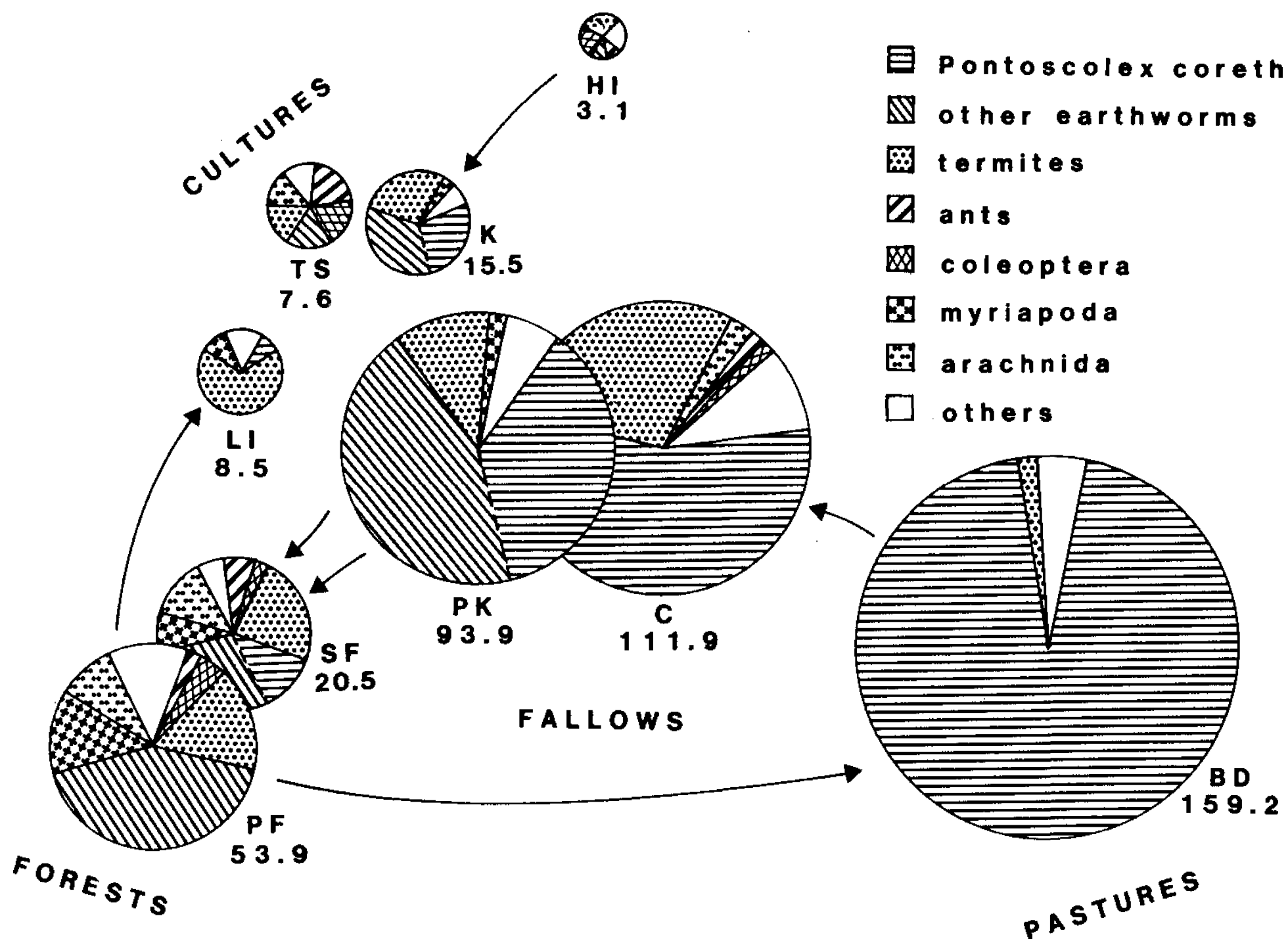


Fig. 4. Distribution of biomass among the main taxonomic units in different types of land-use. Abbreviations as in Fig. 2. Size of circles is proportional to biomass. Mean biomass ($\text{g} \cdot \text{m}^{-2}$) indicated below abbreviation of type of land-use.

4. Discussion

Soil macroinvertebrate communities at Yurimaguas are dramatically affected by land management. Primary forests have a rather diverse and abundant fauna with the population density $4,303 \text{ ind} \cdot \text{m}^{-2}$ and biomass 53.9 g being 2 to 3 times higher than in similar environments in Mexico (LAVELLE *et al.*, 1981; LAVELLE & KOHLMANN, 1984), Nigeria (MADGE, 1969), and South East Asia (COLLINS, 1980; LEAKEY & PROCTOR, 1986). Clearing and cropping soon destroy most of this fauna. In high input cultivated plots, biomass is reduced to 6 % of that in the primary forest and population density to 17 %. Half of the taxonomic units have disappeared. Traditional and low input systems have similar though somewhat less dramatic effects. After 6 months of a Kudzu legume short fallow, soil macroinvertebrate communities had started to grow; biomass was more than 5 times that measured in high input cropping, principally due to a development of populations of the ubiquitous polyhumic endogeic earthworm species *Pontoscolex corethrurus* and humivorous termites.

Pastures have the highest biomasses (82.3 to $159.2 \text{ g} \cdot \text{m}^{-2}$) but the lowest population densities (922 – $2,347$) and taxonomic richness (20 – 27) due to the overwhelming development of populations of *P. corethrurus* which represent 82.3 to 95 % of biomass. A four years *Centrosema* legume pasture following one year association of Legumes + grasses had a rather similar community.

Finally, the peach-palm plantation (*Bactris gasipaes*) with a Kudzu cover had a large earthworm community with forest and pasture (*P. corethrurus*) species and high population densities of termites and epigeic litter detritivores.

The 15 year-old secondary forest had a soil invertebrate community close to that of the primary forest. Population density was of the same order ($4,072$), but biomass (20.6) was 2.6 times less and

only 27 taxonomic units have been recorded compared with 41 in the primary forest. Earthworms were dominant in biomass with relatively low, but constant populations of *P. corethrurus* which is normally absent from primary forest.

These results clearly point to the detrimental effect of cropping on soil macrofauna especially on earthworms of all ecological categories and litter epigeic fauna. Termites are more resistant and may have high local abundance.

Pastures are very favourable to the development of high populations of *Pontoscolex corethrurus*. This confirms previous observations in a large number of moist tropical grasslands (LAVELLE *et al.*, 1987) where biomasses of 500 to 1,500 kg ha⁻¹ have been recorded. Pastures have however, low abundance of other soil invertebrates, and earthworm species from the original primary forest are totally absent.

Legume fallows show a slow though significant recovery of communities. Peach-palm plantations with a legume Kudzu cover had a rich and diverse community. This type of association of a tree culture with a dense legume cover allows the best development of both forest and open-land populations and may serve as a reservoir for the colonization of adjacent plots with contrasting types of land-use.

Beyond the observation of clear patterns in the effect of land-use on soil macroinvertebrate communities, these results clearly point out the problem of colonization of soils by adapted fauna after major perturbations. Colonization seems to be a rather slow process as is indicated by results of the Kudzu short fallows. It largely depends on the presence of potential colonizers in adjacent plots as well as on the size and shape of the area opened for colonization. The peregrine earthworm *Pontoscolex corethrurus* appeared to be a key species which is frequently present in disturbed areas and may build up very large populations in pastures. The effect of such populations on the conservation of soil fertility is expected to be important (LAVELLE, 1988b). However, colonization of new habitats is slow and only possible if populations are present in adjacent plots and/or individuals are introduced and reproduce (MAZAUD & BOUCHÉ, 1980; LEE, 1985). Further research should carefully examine rapidly changing environments, (e.g.) from secondary forests to cropping or pasture and further stages of fallows. The reason for the extremely low abundance of invertebrates in crops should be identified in order to design practices which allow a better conservation or development of these useful agents of fertility. These practices may be as diverse as having long and relatively narrow plots; keeping wooded refuges, having a wooded plot and a grassland on either side of a cultivated plot; and using surface mulches to encourage soil faunal activity by providing food and shelter or introducing adapted species to accelerate the constitution of an active community.

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Synopsis: Original Scientific paper

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Soil macroinvertebrate communities have been quantitatively assessed in 11 different types of land use by handsorting ten 25 cm × 25 cm × 30 cm samples, during the rainy season.

Primary forest had the largest diversity and population density (430 ind · m⁻²) and a high biomass (53.9 g m_h × m⁻²) dominated by earthworms, termites and Myriapoda. Cropping severely depleted this community with a minimum population density of 730 ind · m⁻² and a biomass of 3.1 g in a high input system, 6 months after clearing the forest.

Pastures had low diversity, population density in the range 922–2,347 and biomass as high as 82.3 to 159.2 g · m⁻² due to colonisation by the peregrine earthworm *Pontoscolex corethrurus*. Short fallows still kept patterns of the previous type of land use. Finally, peach-palm plantations with a legume cover had the second highest diversity, and a high biomass (111.9 g) due to the conservation of large part of the original forest fauna and colonisation by opportunistic species of disturbed land.

Key words: Soil, macrofauna, land management, Peru, Amazonia, Oligochaeta, *Pontoscolex cerethrurus*, Termitidae, Glossoscolecidae, Oligochaeta, Myriapoda, biomass, population density, diversity.

Address of authors: PATRICK LAVELLE (corresponding author) Laboratoire d'Écologie de l'École normale Supérieure, 46 rue d'Ulm, 75230 Paris, Cedex 05, France; BETO PASHANASI, Estacion experimental San Ramon, INIAA-NCSU, Yurimaguas, Loreto, Peru.